Hydraulic Tunnels

Hydraulic Tunnels

- Hydraulic tunnel is an underground water conduit formed by excavation without disturbing the surface.
- Water can be conveyed from tunnel through high ground or mountains in rugged terrain where the construction of the surface line is difficult.

Advantages:

- Less environmental effect --> Reduction of land acquisition, forest clearance, etc.
- Adopts shortest possible route so head loss is minimum.
- Optimum space consumption and the natural landscape is not disturbed.
- Less Seismic effect

Disadvantages:

- Normally high construction cost
- High constructions risks
- The construction period is normally long

❖ Based on purpose or function, hydraulic tunnels may exist in following forms:

- Interconnection tunnel of reservoirs
- Diversion tunnel during construction
- Spillway tunnel
- Power tunnel
- Tailrace tunnel
- Navigational Tunnel
- Silt Flushing tunnel

❖Pressure and Non- Pressure Tunnel

- Non- Pressure Tunnel: The tunnel in which the flow takes place as free surface exposed to atmosphere. The flow in the tunnel is open channel flow. For e.g.: Spillway Tunnel, Diversion Tunnel, Tailrace Tunnel, etc.
- Pressure tunnel: The tunnel in which the flow takes place with pressure is called pressure tunnel. For e.g.: Headrace tunnel

Hydraulic Design of Tunnel:

i) Free Flow Tunnel (Non-pressure Tunnel)

- Hydraulic design of the free flow tunnel is executed as the hydraulic design of canal.
- Manning's frictional factors are used to compute the head loss in length.

ii) Pressure flow Tunnel:

- Hydraulic design of the pressure flow tunnel is computed as the pipe flow
- The head loss is computed using Darcy/ Weisbach frictional factor. → $h_f = (f.l.v^2)/(2gd)$
- Discharge through a pressurized hydraulic tunnel is calculated using the continuity equation

  Q = A * v

  where Q is discharge in m^3/sec, v is velocity in m/s, A is area in m^2

<u>Velocity in Tunnel:</u>

- Unlined tunnel: 2 to 2.5 m/sec (max)
- Lined tunnels 4 to 5 m/s (max)
- Permissible velocity also depends upon sediment load carried by water (suspended or Bed load),
  - Recommended velocity is 2.5 m/s

Size and Shape of Tunnel

Geometric design (shapes) of tunnel

a) Circular Section
- Suitable when the tunnel is subjected high internal pressure but does not have good quality rock around it
- Most suitable from structural considerations but difficult for excavation (construction)

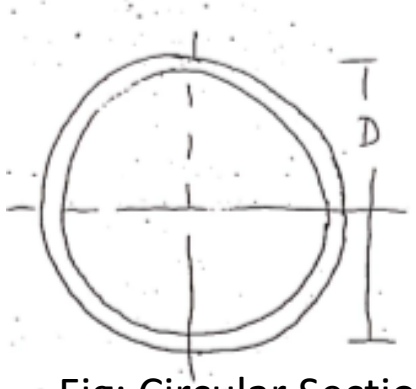


Fig: Circular Section

Cross-sectional area(A) = $0.785D^2$

And, Perimeter (P) = 3.14D

b) D-shaped section:
- Suitable for tunnels located in good quality rocks.
- More working space compared to other sections

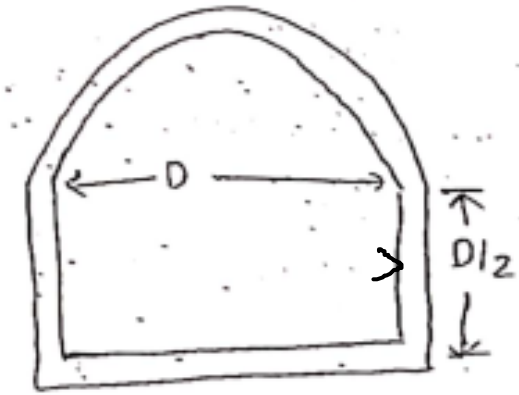


Fig: D-shaped section

Cross- sectional area (A) = $0.8293\ D^2$

And perimeter (P) = 3.57 D

c) Horse-Shoe Section:
- Compromise between circular and D-shaped sections.
- Structurally strong to withstand external rock and water pressure.
- Suitable for moderately good rocks
- Preferred more due to construction techniques.

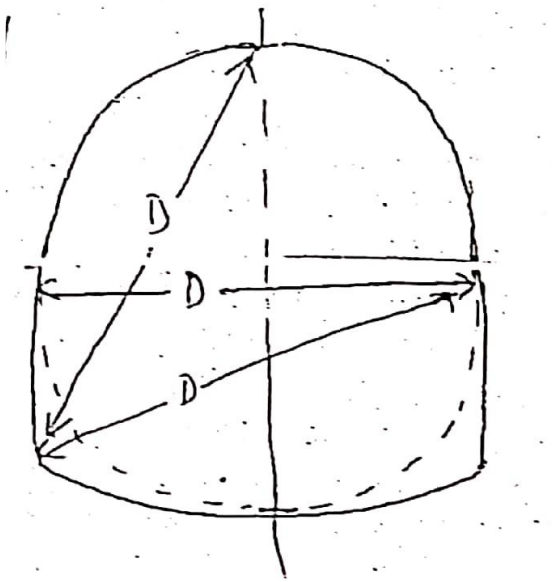
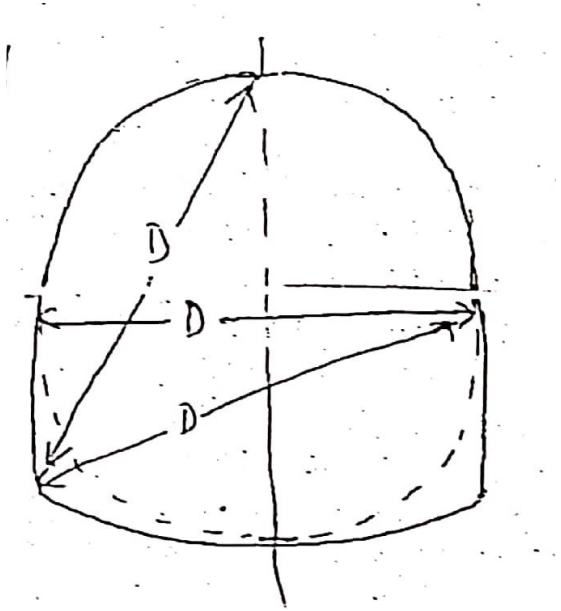


Fig: Horse-Shoe section

Cross-sectional area (A) = 0.8293 D^2
Perimeter = 3.267 D
And Hydraulic radius = 0.2538 D



When the rock is stratified, soft and very closely laminated (sand, stones, slates, micaceous schists) and where rock falls are cause due to high external pressure and tensile stresses in rock, egg shaped section may be considered.
Area of section (A) = 0.854 D^2
Perimeter of section (P) = 3.313 D

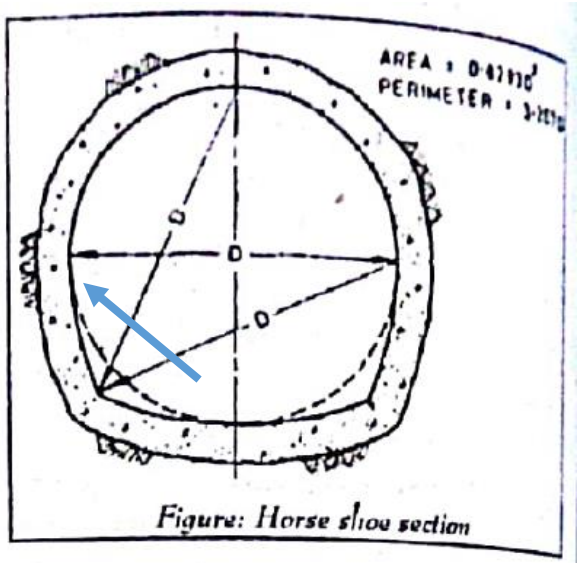


Figure: Horse shoe section

Horse-Shoe or Modified Horse Shoe Section:

Tunnel Alignment:

Some points to be noted during tunnel alignment selection:

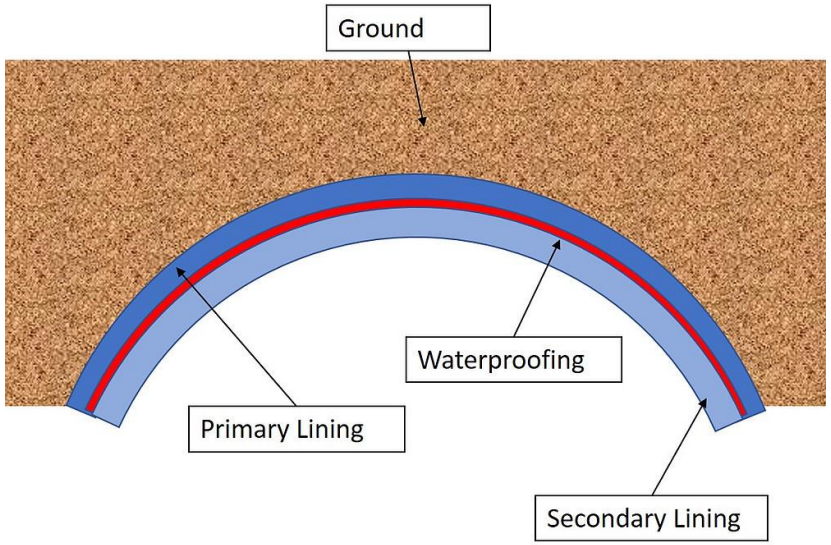
- Shortest as far as possible (economic, minimum head loss).
- Straight as far as possible (bends increase construction cost as well as head loss)
- Easily accessible near the entrance and exit for easy construction.
- Careful selection of the alignment with no weathered, loose or fractured layers

Tunnel Lining

After excavation of tunnel, tunnel lining is done to increase hydraulic capacity of tunnel, to increase strength, to reduce resistance, and to reduce losses from the tunnel.

Advantages:

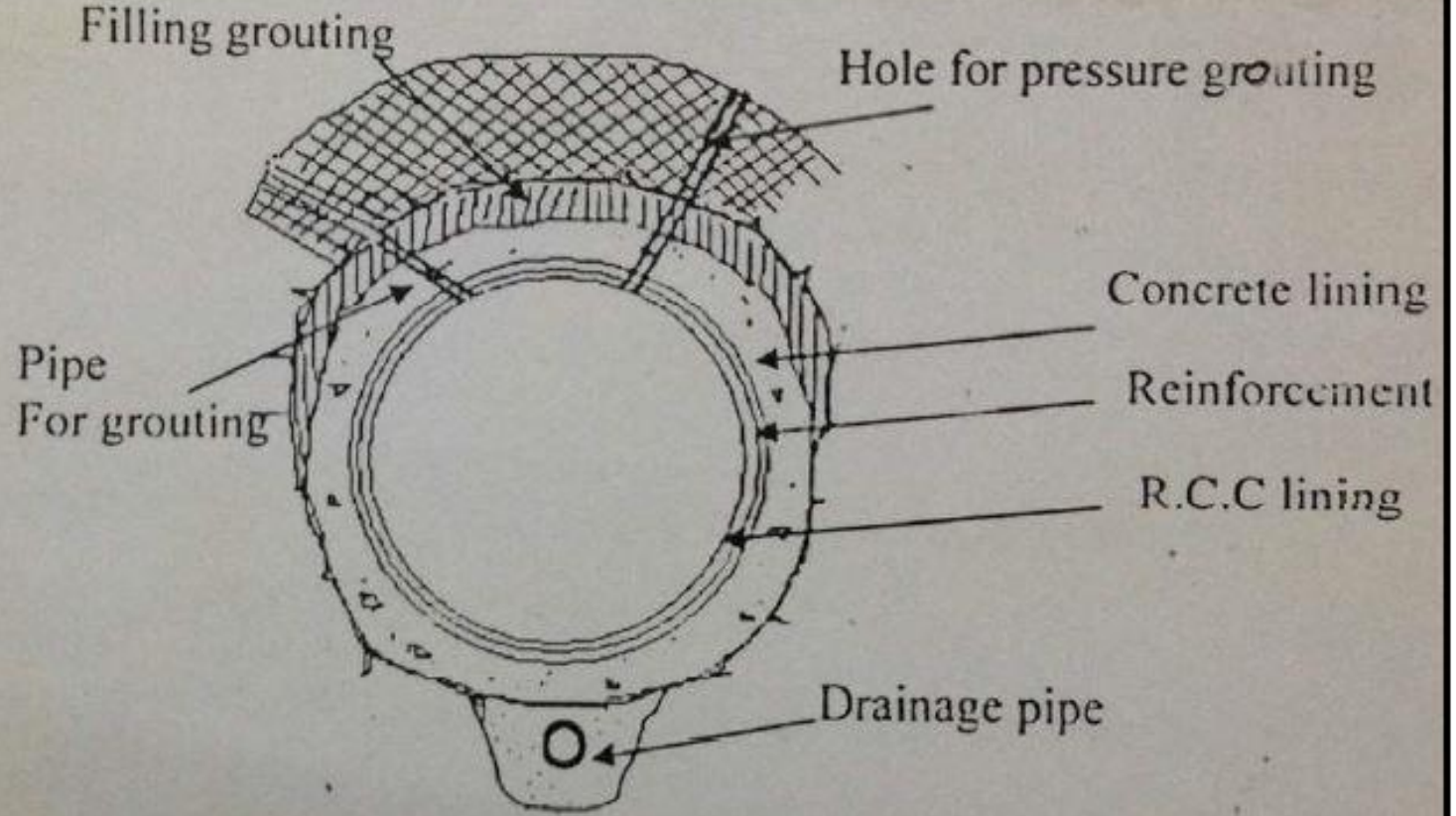
- Acts as a structural unit and transmits part of load to the surrounding rock. So, Structural stability is increased.
- Hydraulic resistance of lined tunnel is much less than that of unlined tunnel. So, it minimizes losses, saves energy and revenue.
- Velocity of water in lined tunnel can be higher than in unlined tunnel. Hence, small section may have better discharge carrying capacity.
- The seepage losses through the tunnel are reduced significantly.



Design of tunnel lining

- The principle factors that should be considered in the design and detailing are:
  - Material (PCC, Shotcrete, RCC, Steel)
  - Required performance criteria
  - Geological conditions
  - Design Life
- PCC lining is preferred when tunnel walls are to support high outside pressure due to rock, but low inside pressure
- While internal pressure is high, RCC or Steel linings are required.

Typical section of pressure tunnel:

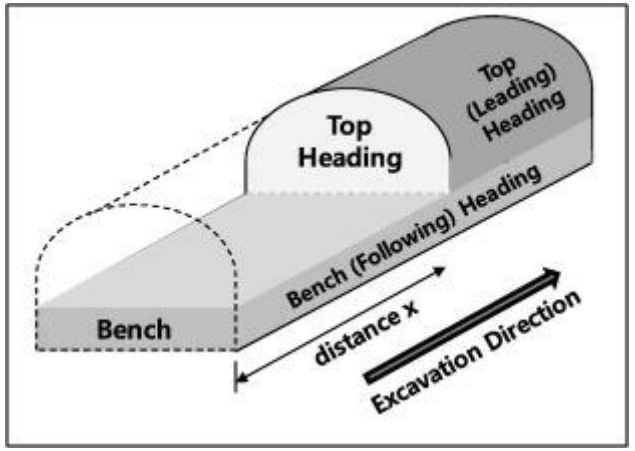


Pressure Tunnel

Shotcrete

Tunneling method:

1) Heading and Benching
2) Full face blasting
3) Tunnel Boring Machine (TBM)
4) Drilling and blasting
5) Cut and Cover Method
6) New Austrian Tunnel Method (NATM)

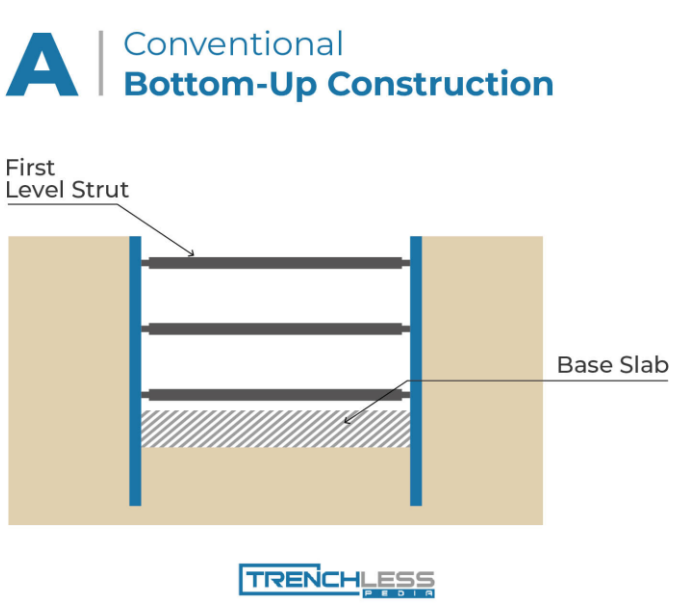


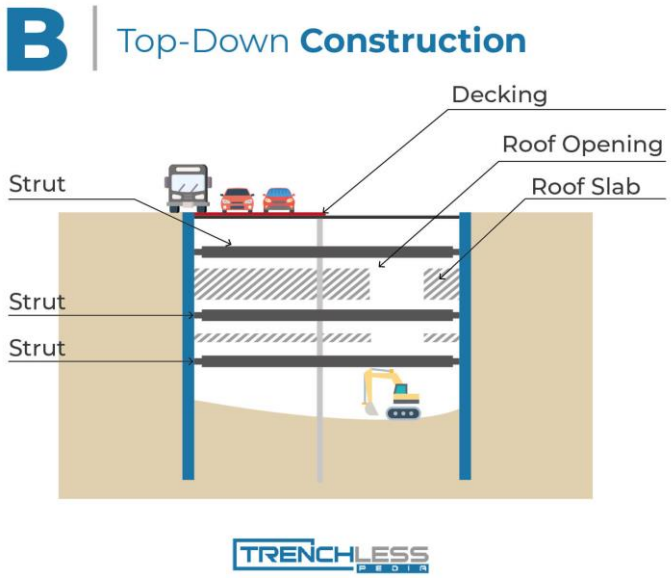
1) Heading and Benching:
   - An old technique
   - Only part of total tunnel cross-section is excavated first which is known as heading.
   - This part is then enlarged to the required size.
   - Heading may be at top, middle or bottom.

2) Full face blasting:
   - A comparatively new method adopted
   - Entire tunnel section is excavated uniformly.
   - Suitable for tunnel passing through strong ground rocks.

Cut and Cover Methods

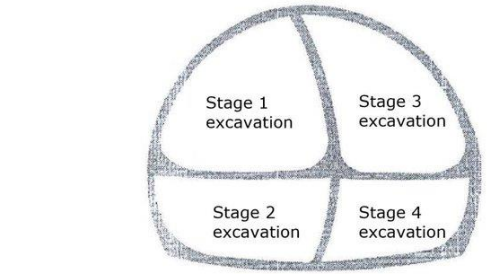
- Cut and cover is the oldest method of tunneling: the basic concept involves the digging of a trench, the construction of a tunnel, and then returning the surface to its original state.

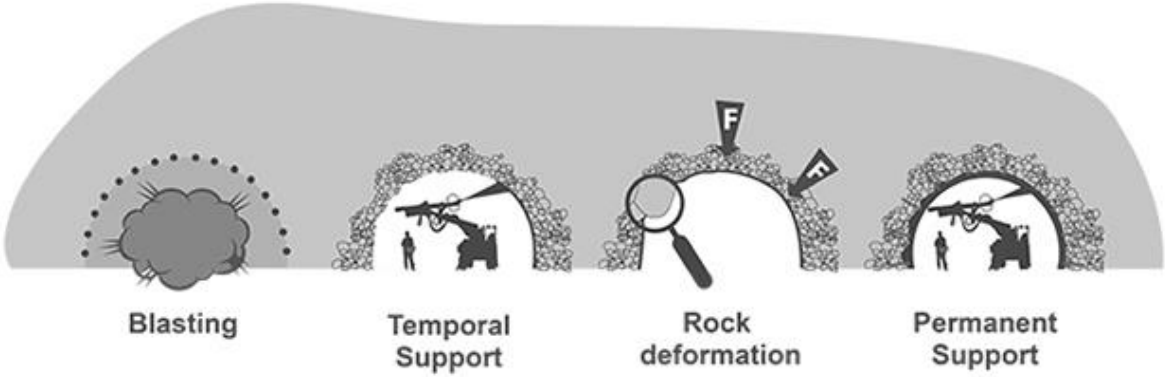


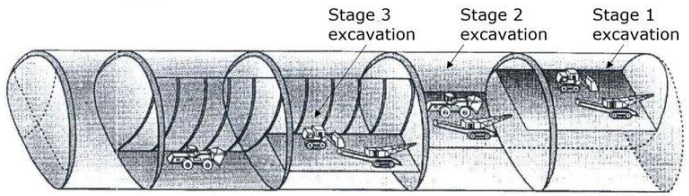


New Austrian Tunnel Method (NATM)

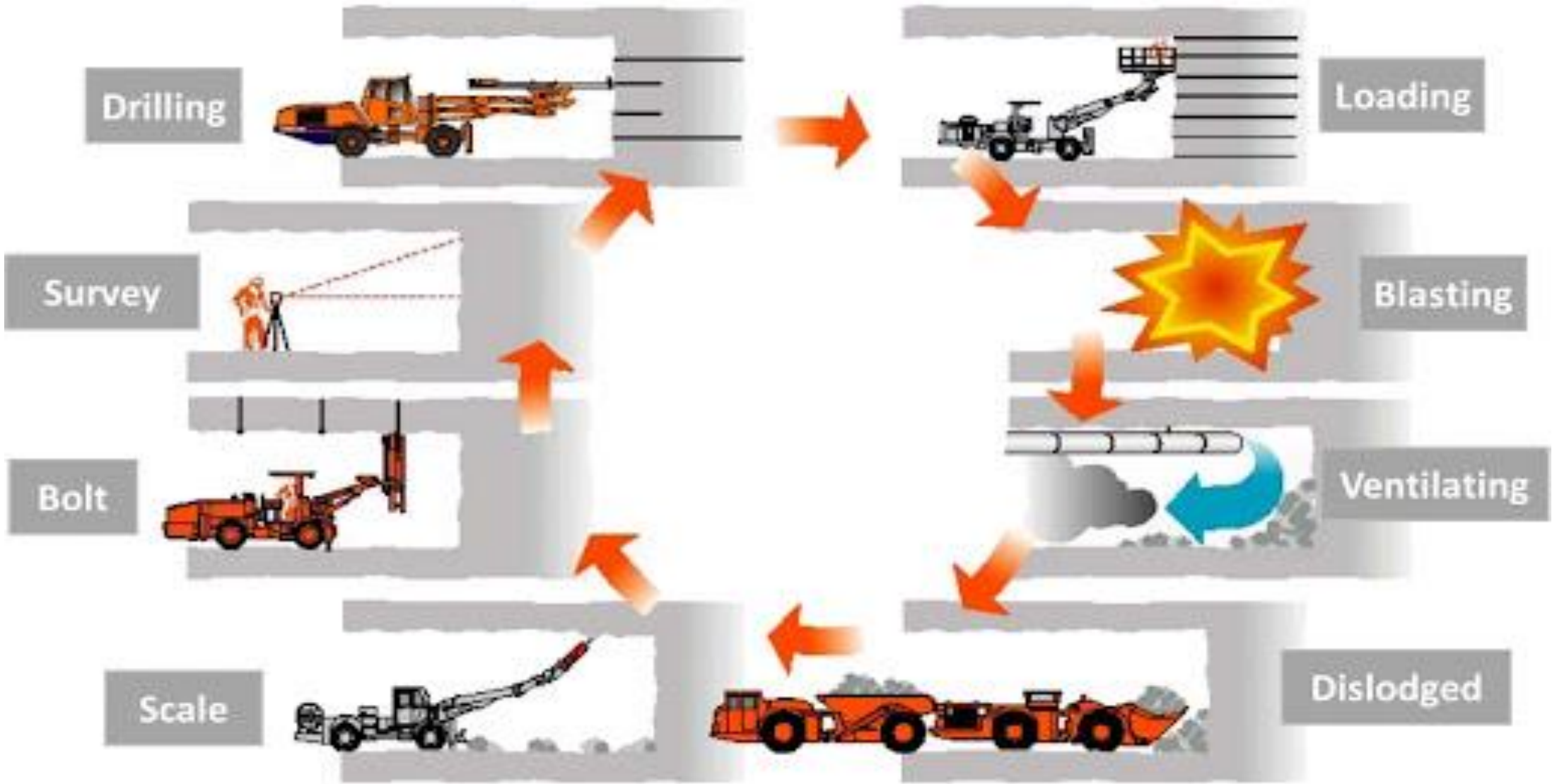
- NATM is both a construction method and a design philosophy. The philosophy looks to use the strength of the surrounding soil to the greatest extent possible to strengthen the tunnel structure.
- The NATM construction method is about flexibility—drilling and designing depending on the results of the ongoing monitoring.
- NATM is best suited for short-range (> 2 km) tunnels in regions with variable soil conditions.







Drilling and Blasting



3) Tunnel Boring Machine (TBM)

- Full face of tunnel is excavated mechanically by means of tunnel boring machine.
- Latest technology
- Suitable for long tunnels.
- Suitable for easily accessible sites (road).
- Cost: Expensive compared to other methods
- Fast, easy and safe construction in weak to strong ground rock conditions

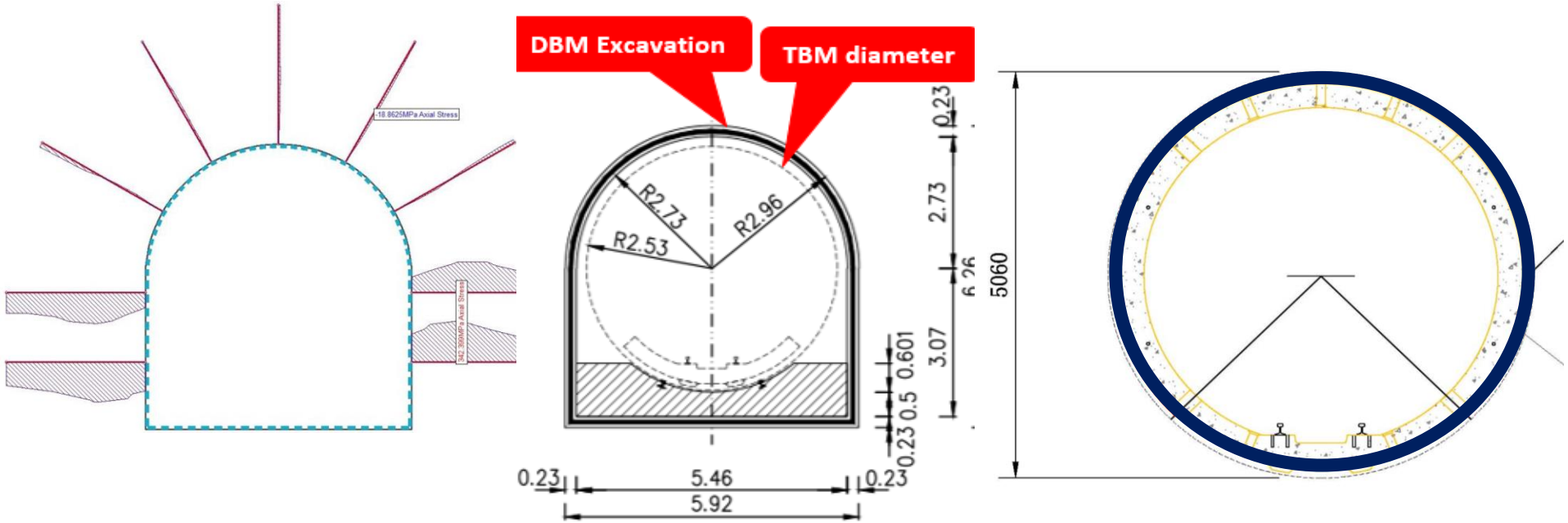
Tunnel Excavation by DBM vs TBM

DBM

Shotcrete, Shotcrete with wiremesh, Rockbolt, Lattice girder, RCC etc
Construction Period-Long

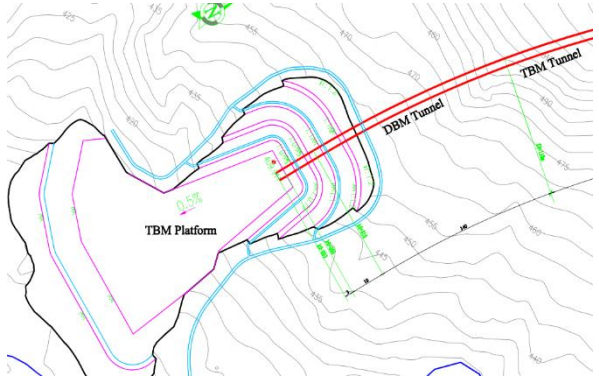
TBM

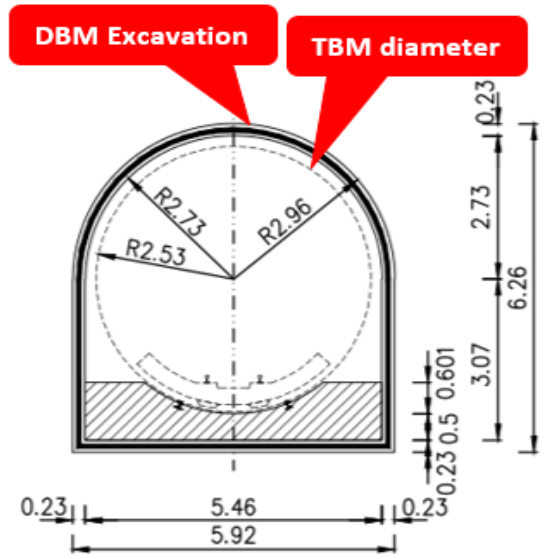
Precast Segment erection with pea-gravel & grouting for extra excavation, Probe drilling.
Construction Period-Short



Tunnel Excavation by **TBM costs** about **double of DBM**, but is about **3 times fast in construction** (average **28.65m/working day** in BBDMP along with RCC Segment)

Preparation of Inititial 150m by Drilling & Blasting

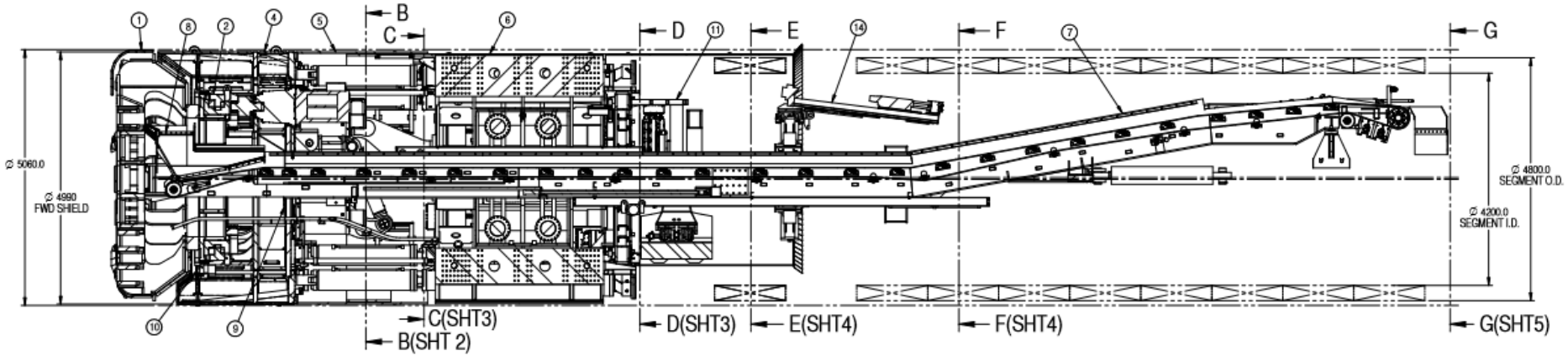




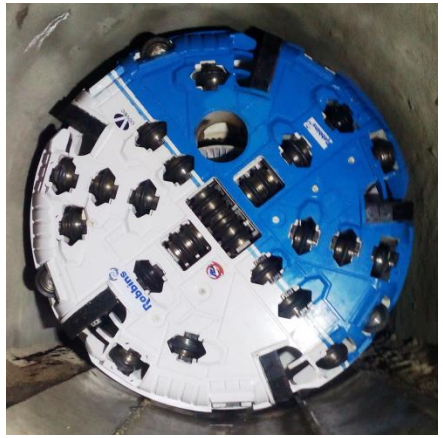
Tunnel Excavation by DBM Method (150.7m)

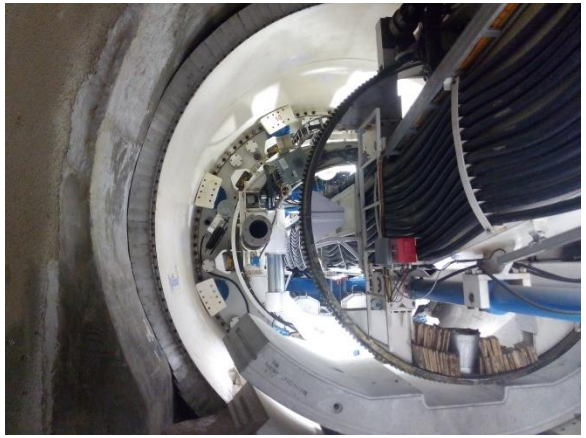
Started on Jan 1, 2017 & Completed on June 2, 2017

15m TBM Front Covered Part out of 274m



TRC P/N 1101231
Ø5.06m DOUBLE SHIELD GENERAL ASSEMBLY





Transport of TBM

Arrival at Kolkata Aug 5,2017
Vehicles (total 53) arrived at Nepal Customs on Aug 26, 2017

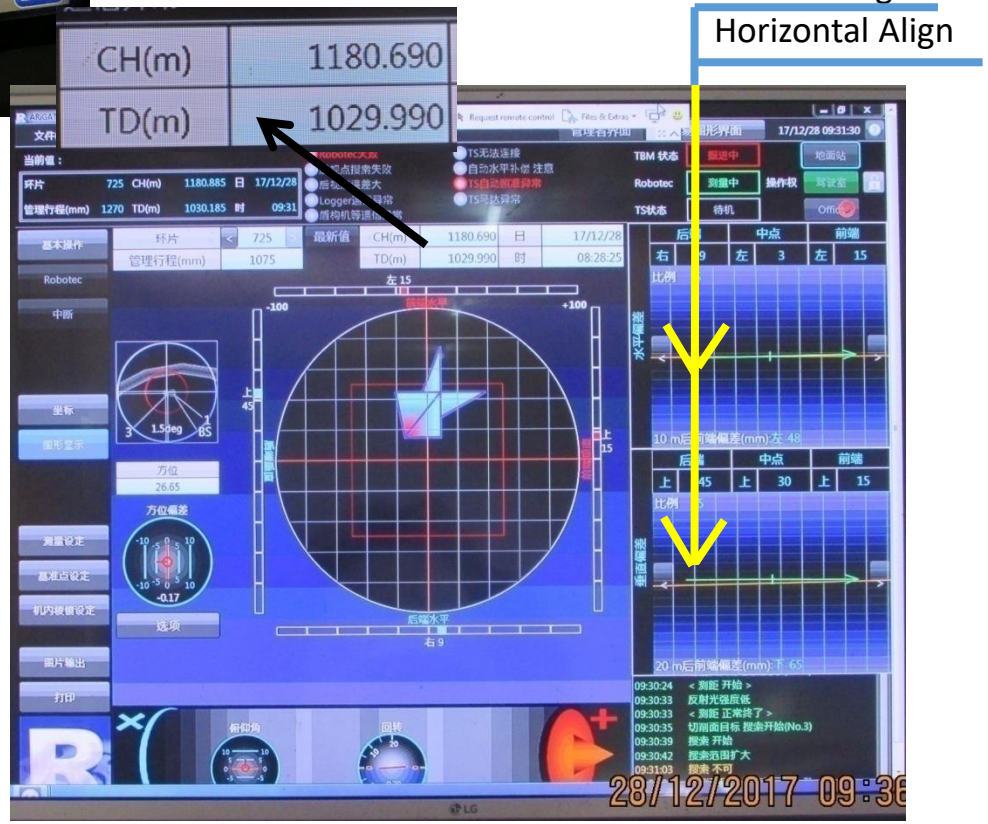
Max Load = 67t
Total Load = 1056t

TBM arrival at job site Sep 13,2017

Tunneling (Excavation)

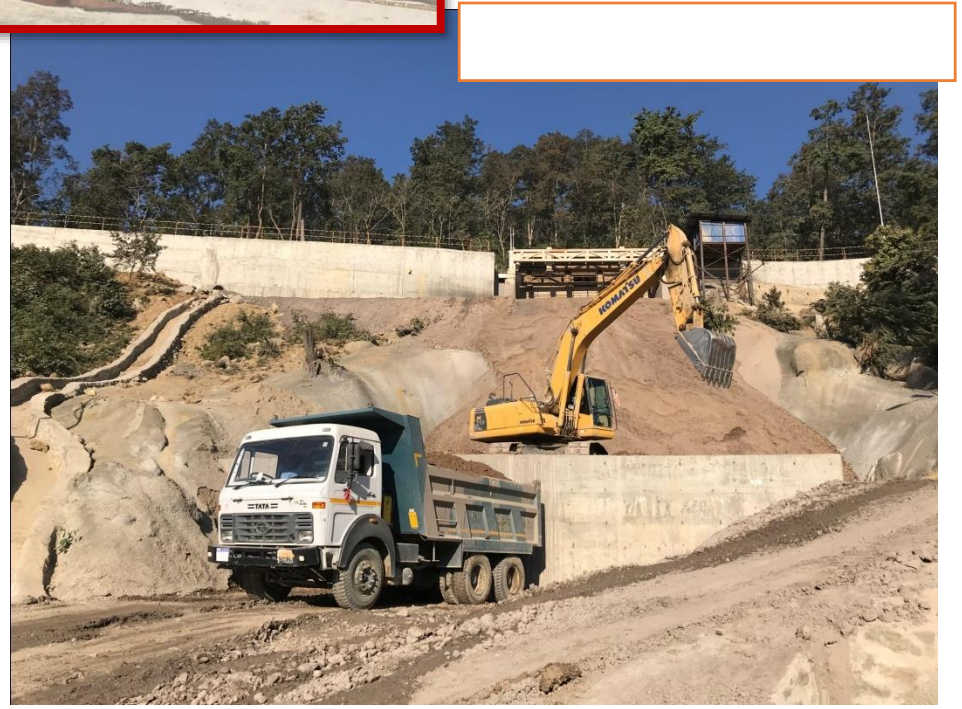
All digital input for operation from Operator's console

- Excavation (Mechanical, Hydraulic, Electrical, Electronics
- Vertical, Horizontal, Curvature



Mucking

- Muck is disposed from TBM by conveyor belt to muck cart
- Muck cart dispose at mechanized disposal equipment
- Loaded to disposal truck by backhoe



Erecting the Bottom and Lateral Segment

1st time Water Ingressing at 1175m on Dec 27,2017 with 65 Ltr/s

2nd time water ingress at ch 1+337 with discharge of 75 Ltr/s on 2018 Jan 6, suppressed by continued excavation with less speed

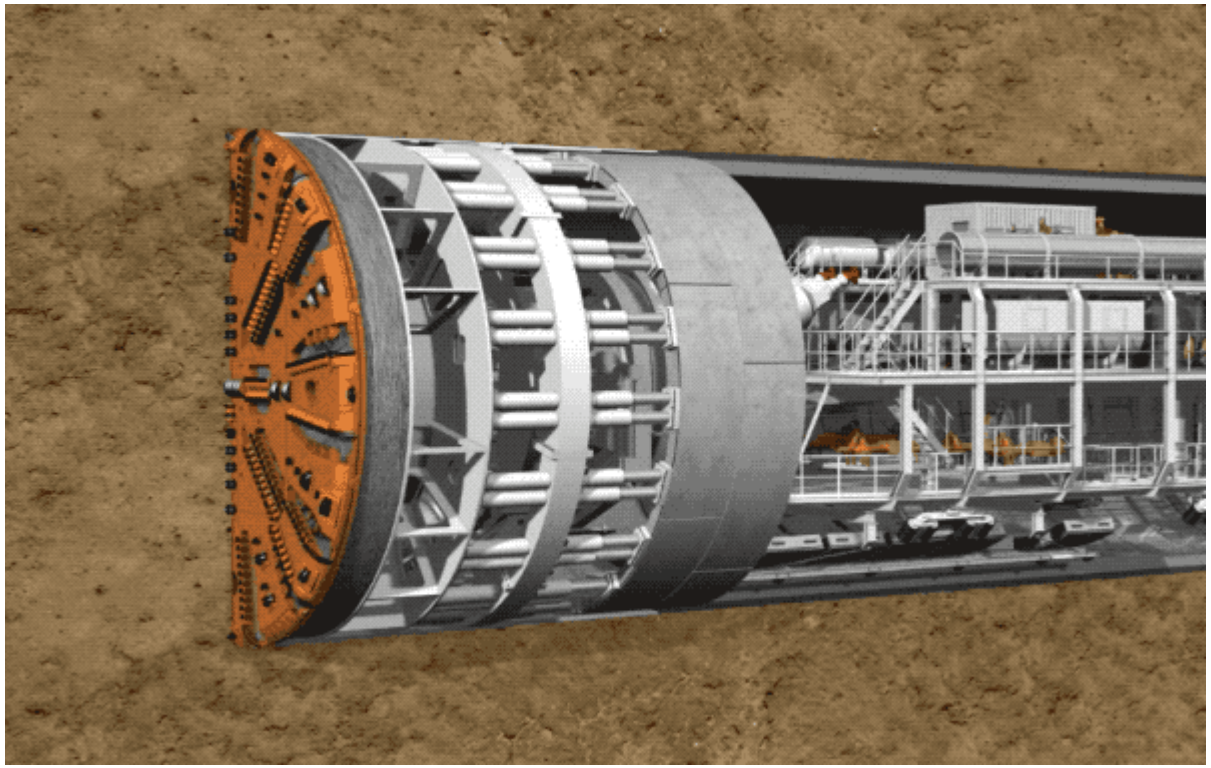
1st time TBM Stuck at Ch. 8+588 on 2018 Oct 15 due to unequal rock at face along with little water ingress & Strike nearly parallel to tunnel alignment. Resumed excavation after 8 day later by making bypass tunnel

Segment Stacking
(Total 34550)

Tolerance of 1400mm Segment width is 1mm and 3mm for other dimension

After Breakthrough (Intake Site Bheri)

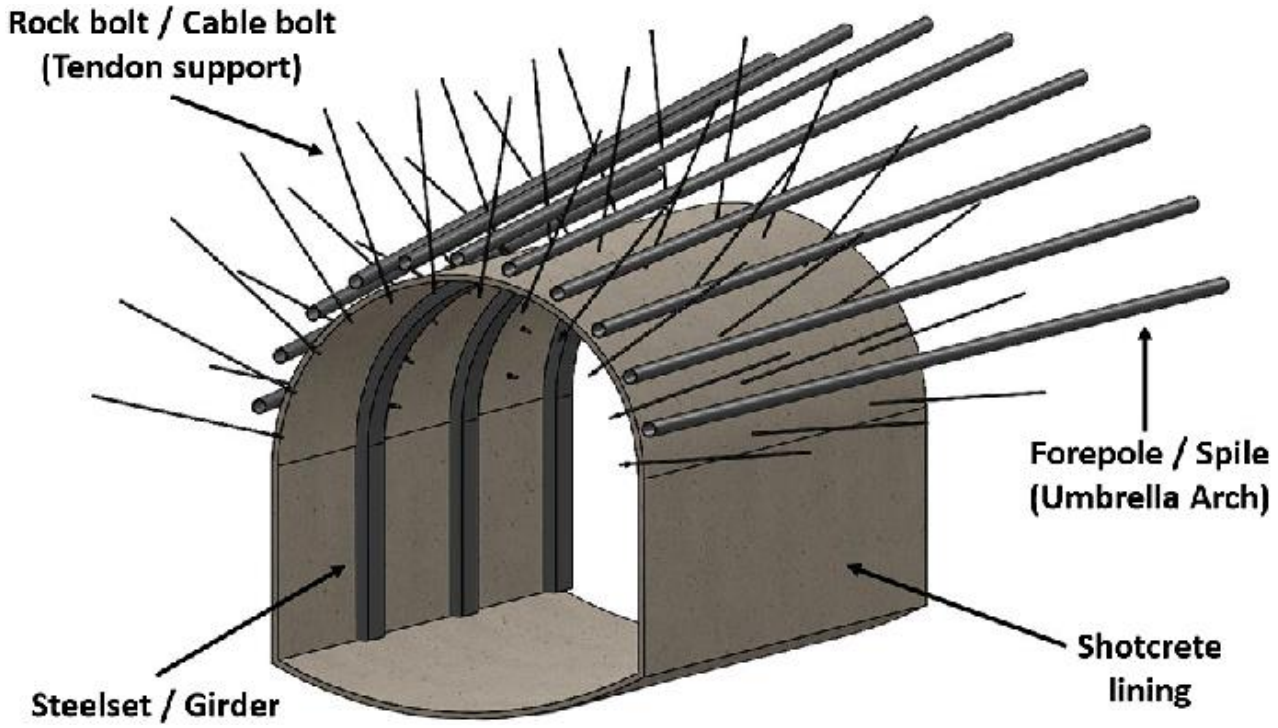
2019 Apr 16 (2076 Baisakh 3)

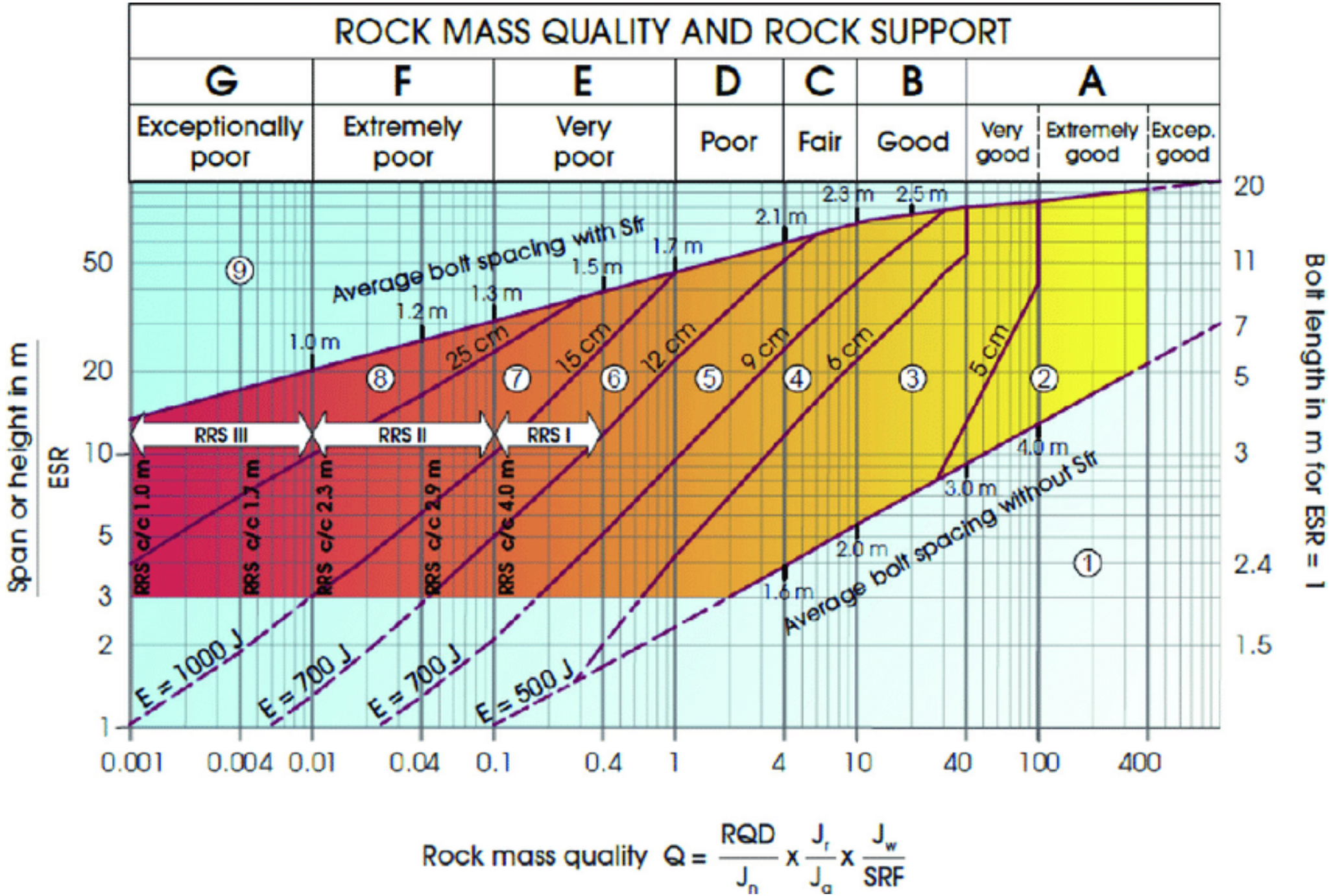


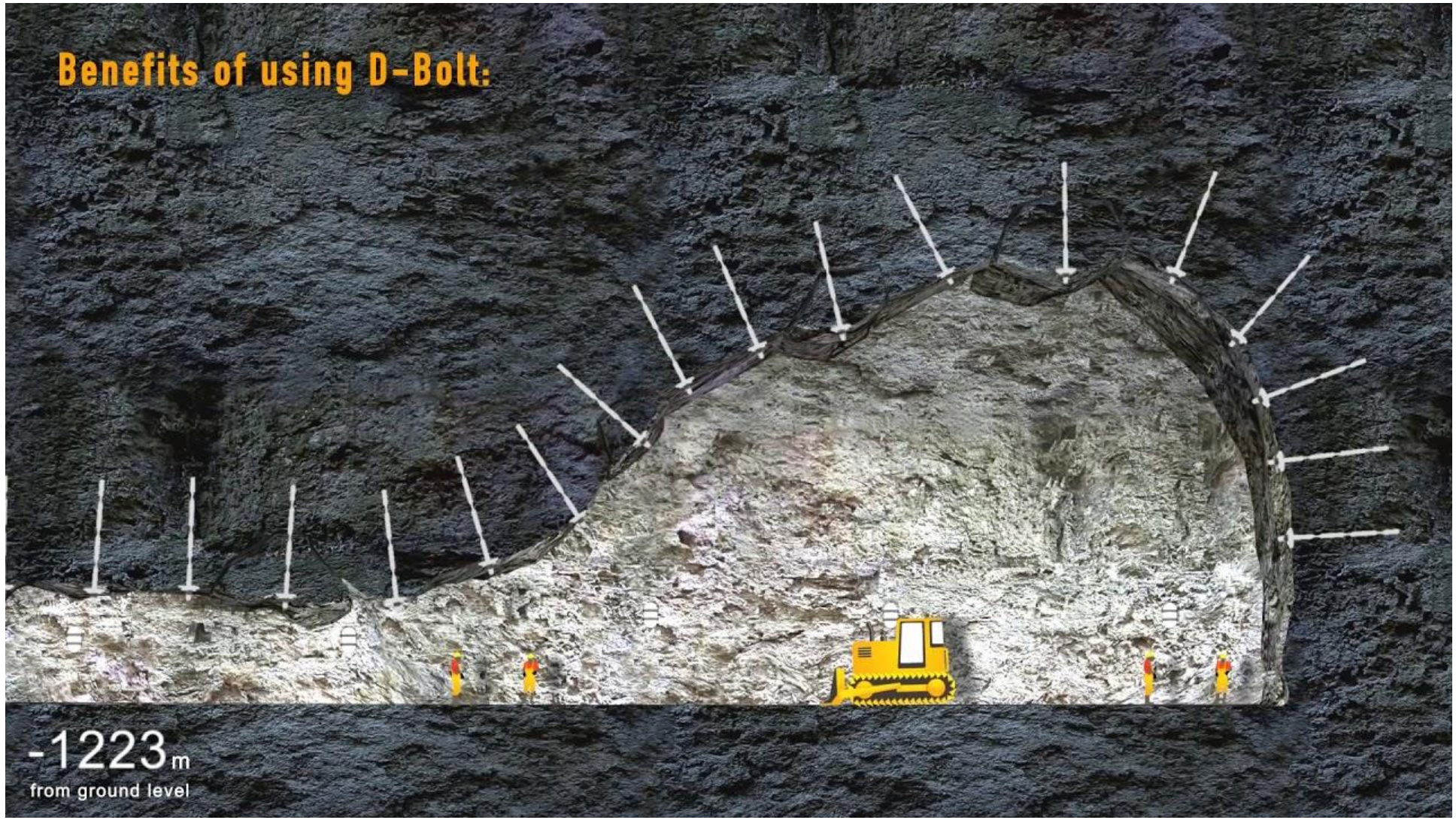
https://www.geotech.hr/wp-content/uploads/2021/02/faze_tuneliranja.gif

Support in tunnel:

- Necessity of tunnel support arises from the fact that the excavated rock has tendency to dropout of the roof tunnel.
- Time elapsed between the blasting and beginning of collapse of unsupported roof is called Bridge action period. It may range from few minutes to few weeks.
- Supports are provided by Rock bolts of varying length.
- Rock bolting may be spot bolting or pattern bolting.
- Steel Ribs (Girder) may also be provided to support the tunnel.




ROCK MASS QUALITY AND ROCK SUPPORT
G
F
E
D
C
B
A
Exceptionally poor
Extremely poor
Very poor
Poor
Fair
Good
Very good
Extremely good
Excep. good
Average bolt spacing with Sfr
1.0 m
1.2 m
1.3 m
1.5 m
1.7 m
2.1 m
2.3 m
2.5 m
25 cm
15 cm
12 cm
9 cm
6 cm
5 cm
RRS III
RRS II
RRS I
RRS c/c 1.0 m
RRS c/c 1.3 m
RRS c/c 2.3 m
RRS c/c 2.9 m
RRS c/c 4.0 m
4.0 m
3.0 m
2.0 m
1.6 m
Average bolt spacing without Sfr
E = 1000 J
E = 700 J
E = 700 J
E = 500 J
Span or height in m
ESR
Bolt length in m for ESR = 1
Rock mass quality Q = RQD/J_n x J_r/J_a x J_w/SRF


Benefits of using D-Bolt:
-1223m
from ground level

Videos Link

Bheri Babai Diversion

- https://www.youtube.com/watch?v=Rvl4BxRGbHY
  - https://www.youtube.com/watch?v=wHfoCMSTl74
  - https://www.youtube.com/watch?v=Kz4VcZa-Seo
- Nagdhunga Tunnel (JICA)
  - https://www.youtube.com/watch?v=u-5FyyIFRTQ
- Tunnel construction
  - https://www.youtube.com/watch?v=qvkytMLBKFc

5.2.3. Hydraulic design of tunnel

Basically, there are two flow conditions in the hydraulic tunnel design:

i. Free flow tunnel

Hydraulic design of the free flow tunnel is executed as the hydraulic design of canal and Manning's frictional formula and factors are used to compute the head loss in length.

Manning's formula: $Q = \frac{1}{n} A R^{\frac{2}{3}} S^{\frac{1}{2}} = \frac{1}{n} A R^{\frac{2}{3}} \left(\frac{h_f}{L}\right)^{\frac{1}{2}}$ or $V = \frac{1}{n} R^{\frac{2}{3}} \left(\frac{h_f}{L}\right)^{\frac{1}{2}}$

Where, h_f - Frictional loss in m, V - Velocity of water in the tunnel in m/s, L - Length of the tunnel in m, R - Hydraulic radius in m, n - Rougosity coefficient

For concrete lined tunnel the value of rougosity coefficient n varies from 0.012 to 0.018. For unlined tunnel the value of n depends upon the nature of rock and the quality of trimming.

Table 5.1: Recommended values of n for various rock surface conditions are given below:

Surface Characteristics	Minimum value of n	Maximum value of n
Very rough	0.04	0.06
Surface trimmed	0.025	0.035
Surfaced trimmed and invert concreted	0.02	0.03

ii. Pressure flow tunnel

Hydraulic design of the pressure flow is computed as the pipe flow and the head loss is computed using Darcy/Weisbach frictional factor. Discharge through a pressurized hydraulic tunnel is calculated using a continuity equation with control volume approach: $Q = V^*A$

Where, Q - discharge in m^3/s, V = velocity in m/s, A = area in m^2

Frictional loss is calculated by Darcy Weisbach formula: $h_f = \frac{fLV^2}{2gD}$

Where, h_f - frictional loss, f - friction coefficient, L - length of the tunnel in m, D – *diameter of* tunnel in m, V - velocity of flow in the tunnel in m/s

The friction factor f depends upon the Reynolds number and the relative roughness K_s/D where K_s the equivalent sand grain roughness is and its value depends upon the surface characteristics. For new concrete lined tunnels using forms the value of K_s varies from 0.015 mm to 0.18 mm. For welded steel lined tunnels, the value of K_s ranges from 0.05 to 0.1.

Because of fluctuation in the load demand, the turbines keep an accepting or rejecting water. This causes the flow in the water conductor system to be turbulent. For turbulent flow in the range of Reynolds number between 3000 to 10000 (normally expected in steel lined and concrete lined tunnel) the friction factor is calculated by using simplified formula:

$$\frac{1}{f} = 2.0\, log\left(\frac{1}{2E}\right) + 1.74 \text{ for Colebrook and white Equation}$$

$$\frac{1}{\sqrt{f}} = -2\, log\left[\frac{\frac{K_s}{D}}{3.7} + \frac{2.51}{Re\sqrt{f}}\right] for\ Re = \frac{\rho VD}{\mu} > 2000$$

Where, f is the factor use in the Darcy formula and E is relative roughness given by $E = K_s/D$

Economic dimensioning of tunnel:

1. Economical diameter of tunnel:

According to 'Handbook of Hydroelectric Engineering' – P.S. Migam.

$$D^{7.33} = \frac{19.35\ Q^3 n^2 e u * 10^5}{(E + 0.36L) * O}$$

where,

Q = Discharge

n = rugosity coefficient

e = overall efficiency

u = unit cost of power ($\simeq$ Rs. 7/unit say)

L = unit price of lining ($\simeq$ Rs. 4000/m^3 say)

E = unit price of tunnel excavation

O = Annual operation and maintenance cost

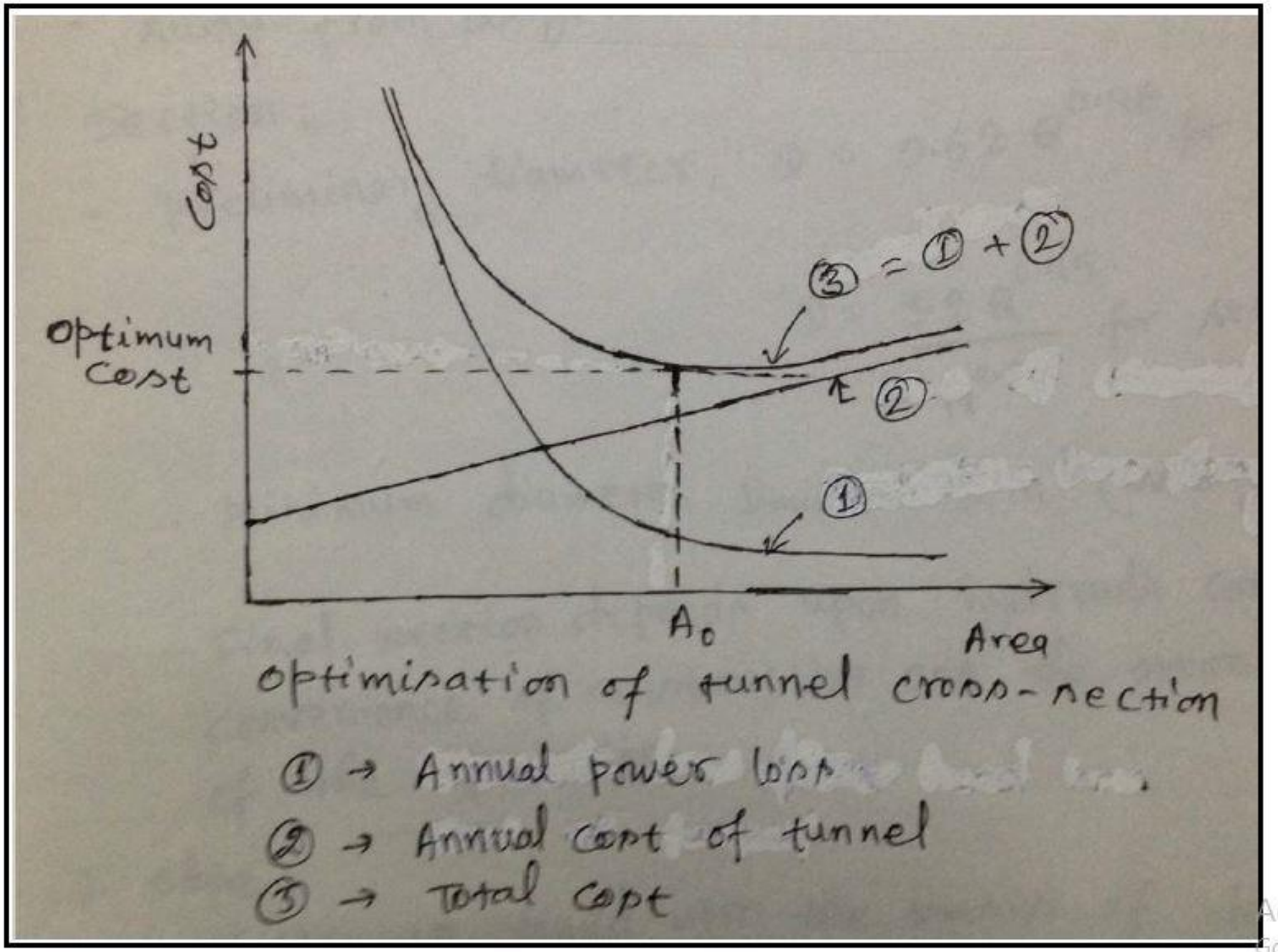
$\simeq$ 8% of total cost.

2. Cost benefit analysis:

$\frac{dC_T}{dA} + \frac{dC_B}{dA} = 0$, will give economical area

C_T = Cost of tunnel per metre

C_B = Capitalized value of annual head loss



Optimisation of tunnel cross-section

① → Annual power loss

② → Annual cost of tunnel

③ → Total cost

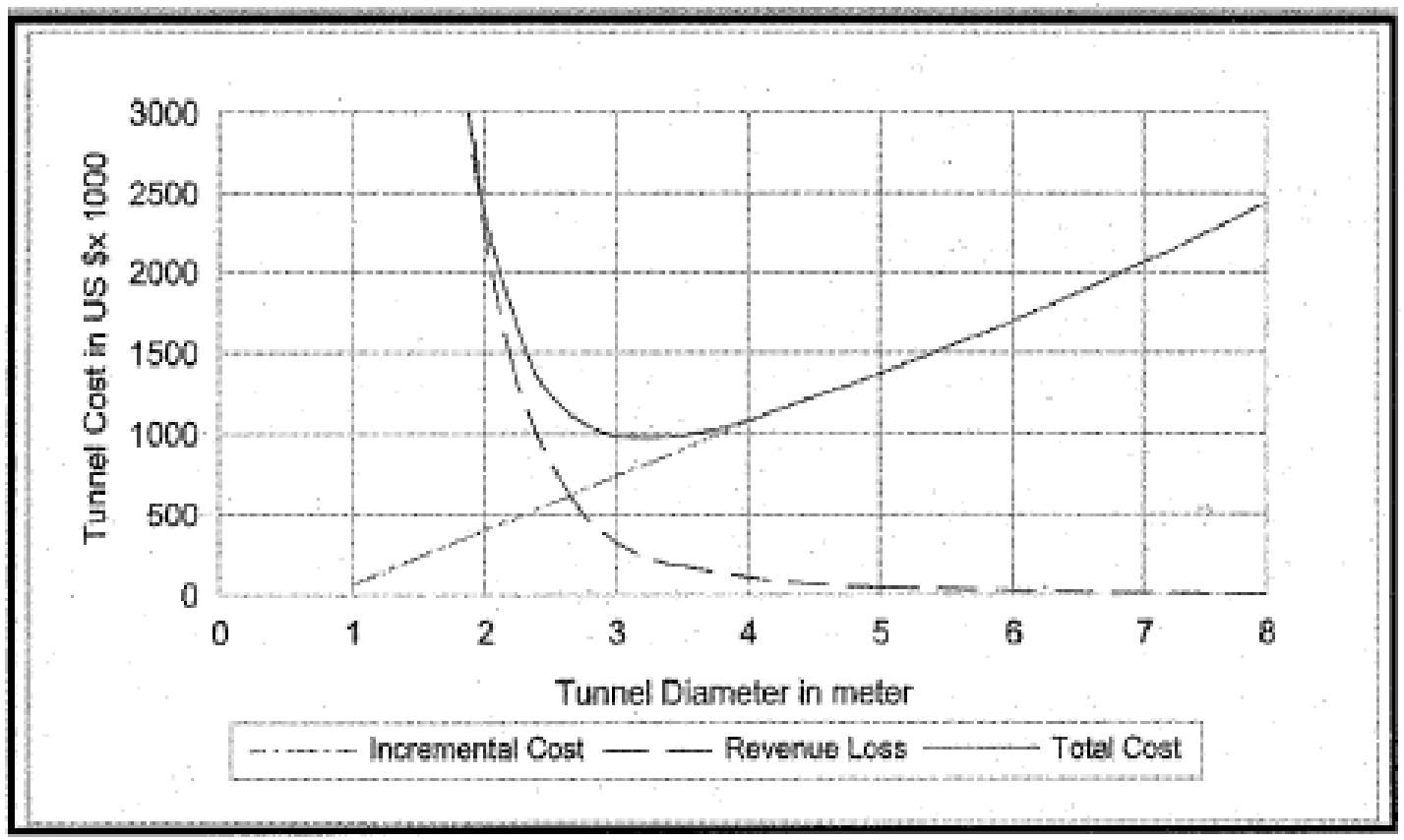


Fig.5.10: Determination of optimised diameter of the tunnel based on economic analyses